Main Injector readiness for NuMI

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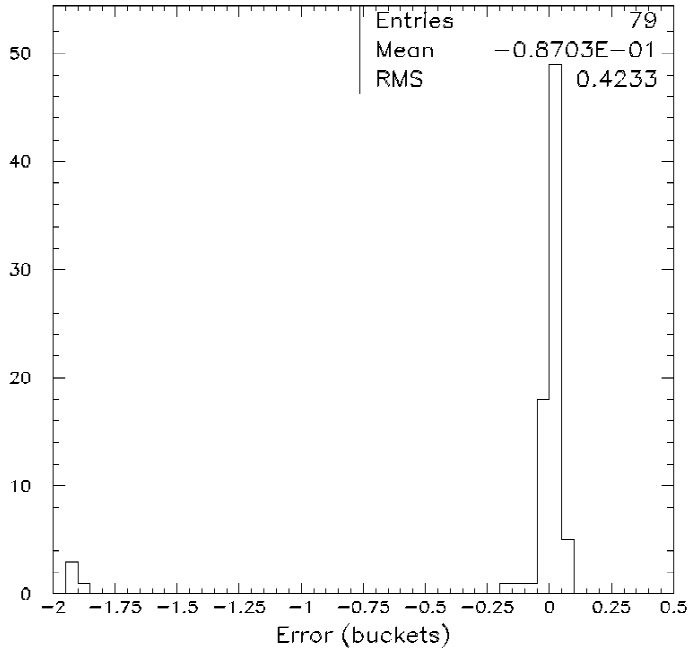
- Goals
  - CD-4
  - Physics running
- Booster issues
- Operational implementations
- Instrumentation upgrades
- Main Injector intensity
- NuMI beam start-up strategy in MI

Goals

- **CD-4 can be accomplished with a dedicated NuMI cycle, at a rate of one per minute, with an intensity of 1-5×10^{12} ppp, within a few hours**
- **For physics running, antiproton stacking and NuMI will share a same Main Injector cycle, with a flattop energy of 120 GeV**
  - a 2 s long Main Injector cycle will accommodate injections of 6 batches, with a total intensity of 3.0-3.3×10^{13} protons/cycle
  - the Antiproton Source requires 1 batch of 0.5-0.8×10^{13} protons
    - an intensity of 0.8×10^{13} protons will be achieved by slip-stacking two batches in 3 Booster ticks (200 ms)
  - 5 batches, for a total intensity of 2.5×10^{13} protons, will be single-turn extracted to the NuMI target
  - beam quality requirements:
    - 95% normalized transverse emittance ≤ 25 π mm-mrad
    - 95% longitudinal emittance ≤ 0.5 eV-s/53 MHz bunch

Booster issues

- **Booster beam has a notch in it (3 buckets wide) to be synchronized with the extraction kicker to avoid beam losses at extraction**
  - Extraction has to be synchronized with beam already present in MI
  - Cogging will synchronize the Booster notch to beam in the Main Injector
- **Cogging shown to work in Booster to ~ 1 buckets**
  - Later intelligent notching is critical, but what is its effect on losses ?
  - ***A study with multi-batch injection into MI scheduled for this week***
- ***Booster longitudinal dampers need to be made operational on cycle $19 (to be tested in the next few weeks)***

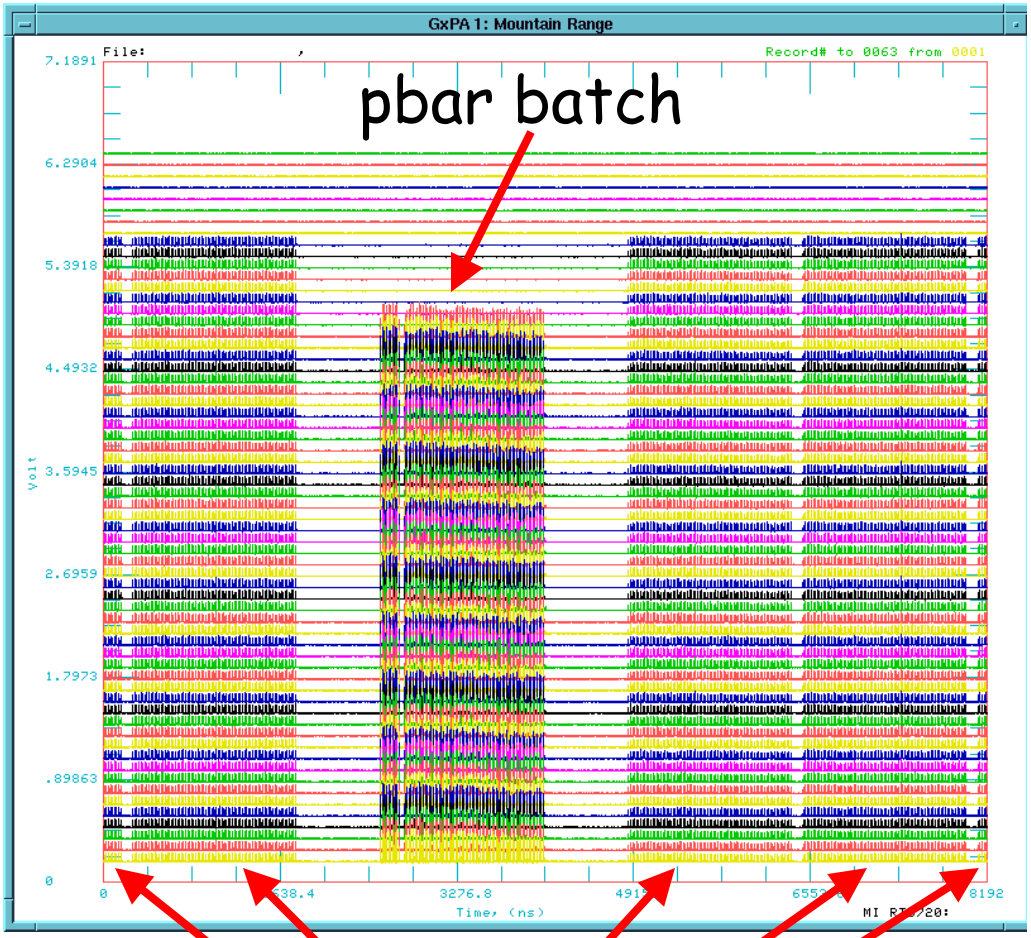


Bob Zwaska, Bill Pellico

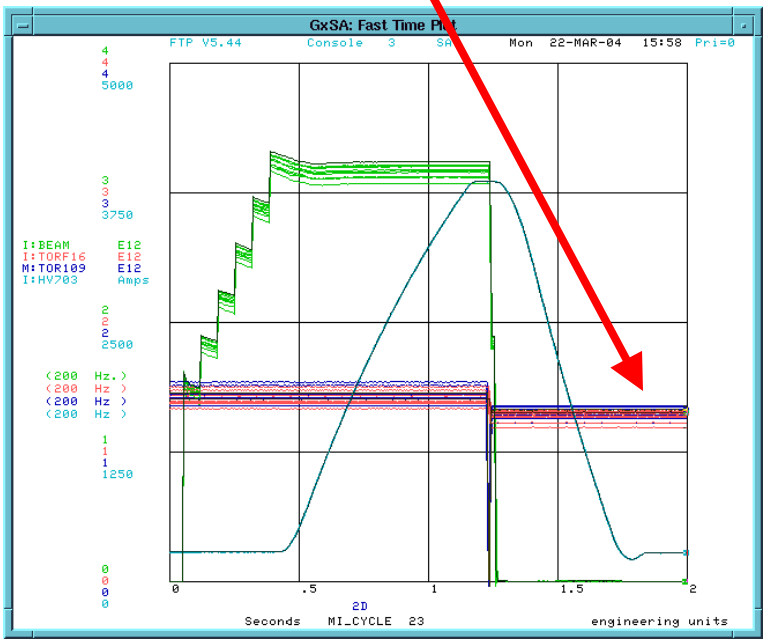
Operational implementations and issues

- **Setting up of an operational cycle for simultaneous antiproton stacking and NuMI operation**
  - the cycle is being developed as a result of NuMI multi-batch and slip-stacking studies
    - we already did a test where we extracted successfully 1 batch to the pbar target, keeping the remaining 5 in MI
- **In order to accommodate mixed mode use of MI for pbar stacking and NuMI (and SY120) we need to revise the TCLK timing scheme of MI**
  - D. Capista, B. Ducar, E. Harms and G. Vogel have agreed on a scheme, which requires the addition of 2 clock events and modifications to the BSSB and other selected hardware
    - ***the plan is to have this mode tested before the summer shutdown***

1 batch to pbar, the rest to NuMI

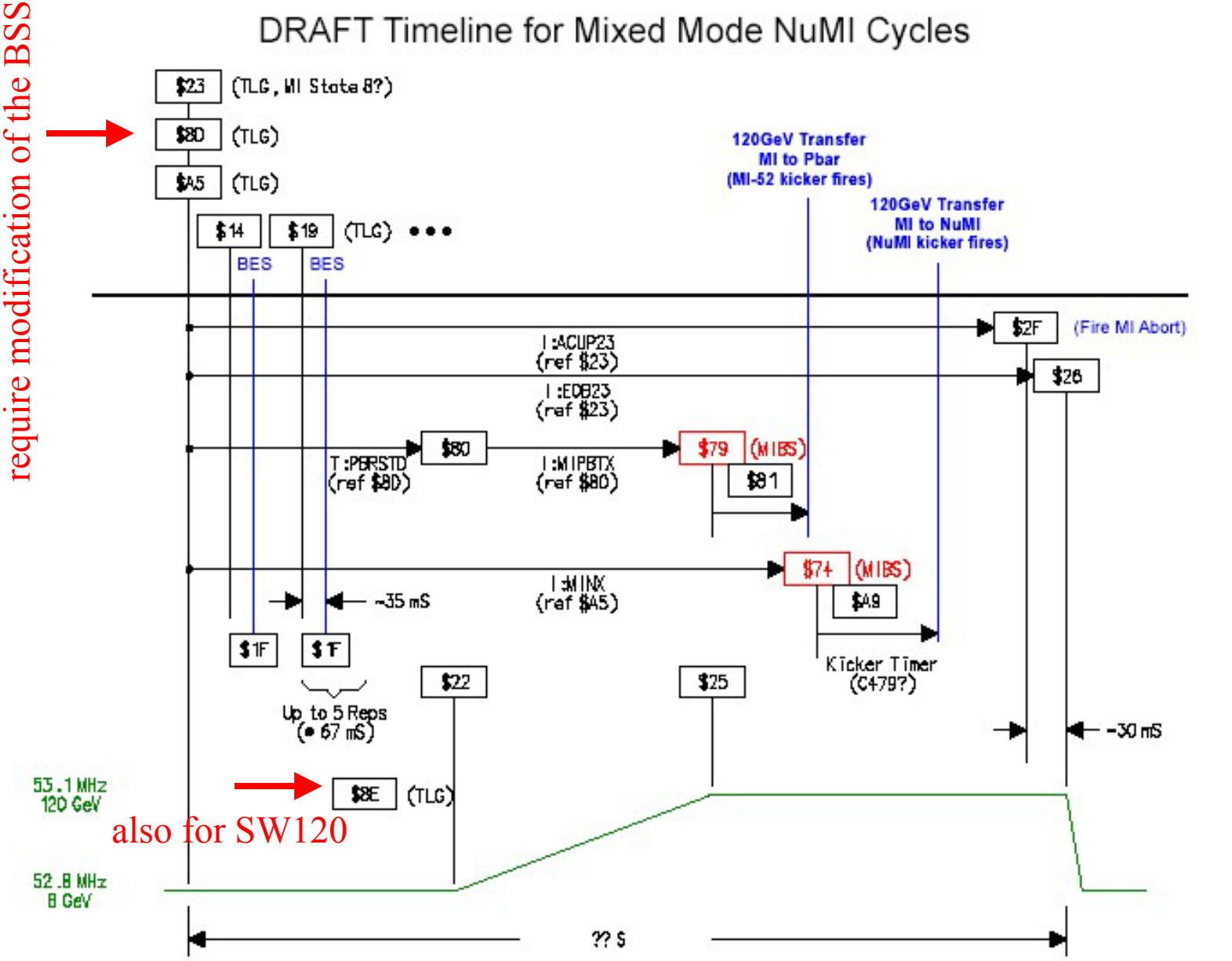


Beam on the pbar target



NuMI batches

pbar stacking reset require modification of the BSSB



- **The pbar batch and the NuMI batches will occupy fixed bucket positions in MI, and it will be possible to control either portion of the beam with its own "beam switch" (pbar and NuMI beam switches)**
  - MI52 and MI602 kicker timings will be kept "fixed"
  - a new LLRF module now supports LLRF feedback loops for beam positioned anywhere in the machine (it has been tested successfully).
- **Setting of extraction bumps around NuMI Lambertsons and kickers**
  - retuning of the closed orbit in MI, in order to reduce correctors currents, with small displacements of a few quads.
    - a first step done after the autumn 2003 shutdown, it needs to be checked again
  - ***final bumps to be checked well before the summer shutdown (by middle July)***

- **Effect of the MI52 kicker rise and fall times on the batches adjacent to the one extracted to the pbar target**
  - we took recently a measurement which shows a transverse emittance increase of ~ 60% in the first 50 bunches of the first NuMI batch
  - ***currently under investigation, we need to take more detailed data using the transverse damper system***
- ***Main Injector shielding assessment needs to be modified to 9.6×10^{16} p/hr by the end of '04***

Instrumentation upgrades

- We are going to operate MI at an intensity which is a factor 6 higher than present, in multi-batch instead of single batch mode, and with 2 separate extractions in a same cycle
- **We need to upgrade some of the instrumentation. It's a matter of reliability of operation.**
  - according to the RUN II plan, **MI Beam Position Monitor upgrade** will start at the end of '04 and finish by the end of '05
    - the present system, as designed, does not operate when MI is loaded with 6 batches in the spacing configuration required to extract one batch to the pbar source
    - ***we will instrument the 602, 604, 606 horizontal BPM's, along with the 607 vertical BPM, with NuMI BPM electronics, capable of batch-by-batch position measurements***

- we are in the process of establishing specifications for new electronics for the **MI Beam Loss Monitor system**, coordinating this effort with a similar one which is in process for the Tevatron system. ***Trying to make it part of the RunII plan …***
  - the present system can provide integrated losses over the acceleration cycle for only 1 BLM/house (typically 1/12)
  - when running multi-batch at high intensity we need to keep a record of beam losses in MI at least around all the Lambertson locations ➥ we need integrated signals for a good fraction of the loss monitors
- we need **batch by batch intensity measurements** along the acceleration ramp. A Fast Bunch Integrator system coupled to an existing RWM detector could provide the measurement
  - ***specifications for the system have been written***
- in order to cope with the large intensity increases in MI, we need to have a fast and reliable way to **measure tunes**
  - ***the plan is to establish a tune measurement system utilizing the dampers***

MI beam quality inputs to NuMI Beam Permit System

- **Requirements on the MI beam have been set**
  - no beam present during the rise time of the NuMI kickers
    - use signal from batch-by-batch intensity monitor
  - NuMI kicker repeatability within 5% (taken care of by EE Dept.)
  - extraction position, both horizontal and vertical, within 2 mm
  - central momentum regulation at flattop within 1×10^{-3} (already taken care of by LLRF and MECAR)
  - MI beam quality (no losses at flattop in the 608 and 612 regions)
- Desirable signals
  - momentum spread $\Delta p/p<2\times10^{-3}$ (from bunch length monitor BLMON ?)
  - proton extraction in P1 line not lossy (are signals fast enough ? **5 BLMs already connected to the Beam Permit System**)
- ***Specifications for the signals are being written in order to proceed with the construction of the electronics***

Digital Damper System

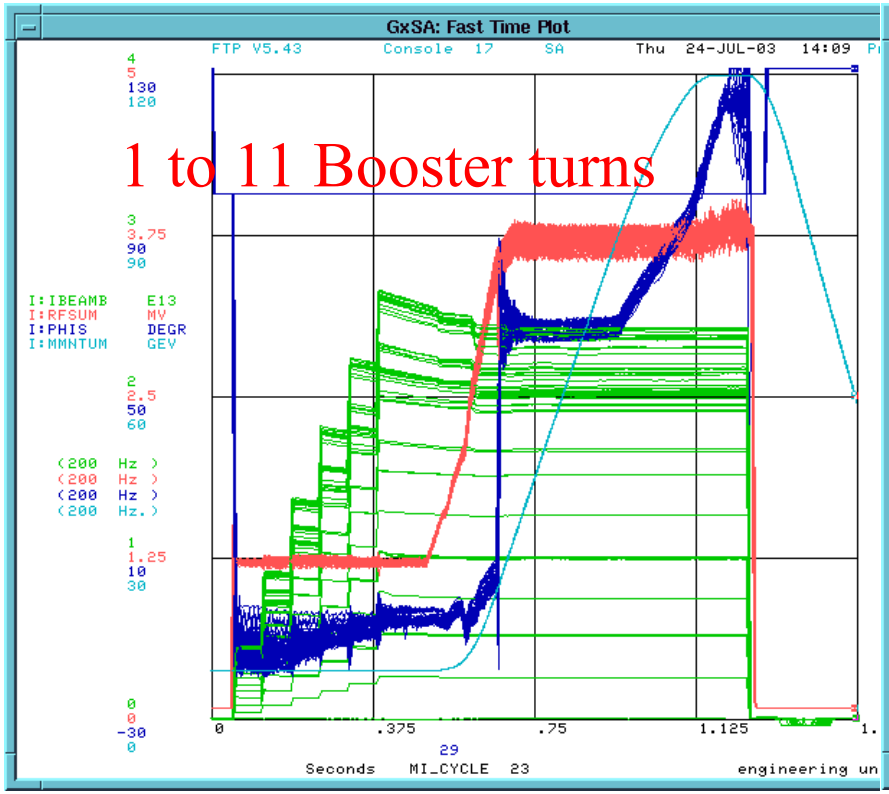
- The system comprises in a single board both transverse (**essential for NuMI**) and longitudinal dampers
- FPGA prototype board installed in spring '03
  - **first tested with transverse dampers**
    - **have been essential to achieve an intensity of 3.3×10^{13} in MI at 8 GeV**
    - presently not operational
  - **after '03 shutdown longitudinal dampers have been successfully tested**
    - operational on \$2B cycle (proton transfer to Tevatron) since Dec. '03
    - operational on \$29 cycle (pbar stacking cycle) since March
- **Final FPGA boards cabled up in March, being debugged now**
  - transverse dampers will be connected to this board first
    - ***beam tests will begin within a month***
    - ***setup a "tunemeter" within end of June***
    - ***recalibration of tune and chromaticity tables in MI***

Main Injector intensity

- **only a few studies performed since '03 shutdown**
  - aimed not to reach high intensity, but addressing operational and instrumentation issues
  - in order to proceed with high intensity multi-batch studies we need
    - ***transverse dampers operational***
    - understand/fix problems caused by the presence of the electrostatic septa (high losses in the 608 region, possibly beam instabilities) ??
    - it would be good to have Booster cogging working by the time of high intensity studies
- ***we need to set-up an automatic tune compensation with intensity***
- ***we still have 4 ½ months to go, but no time to spare***

Multi-batch w/o and with transverse dampers

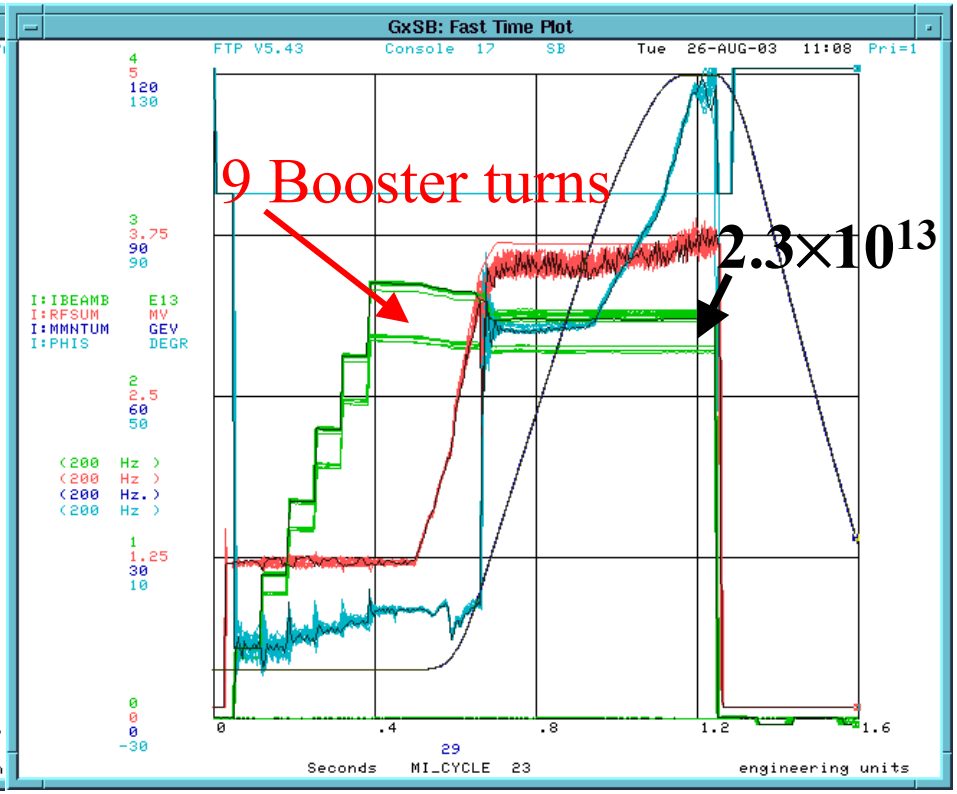
w/o dampers



@ 8.9 GeV/c:

ν_X=26.43, ν_Y=25.42, ξ_X=-20, ξ_Y=-16

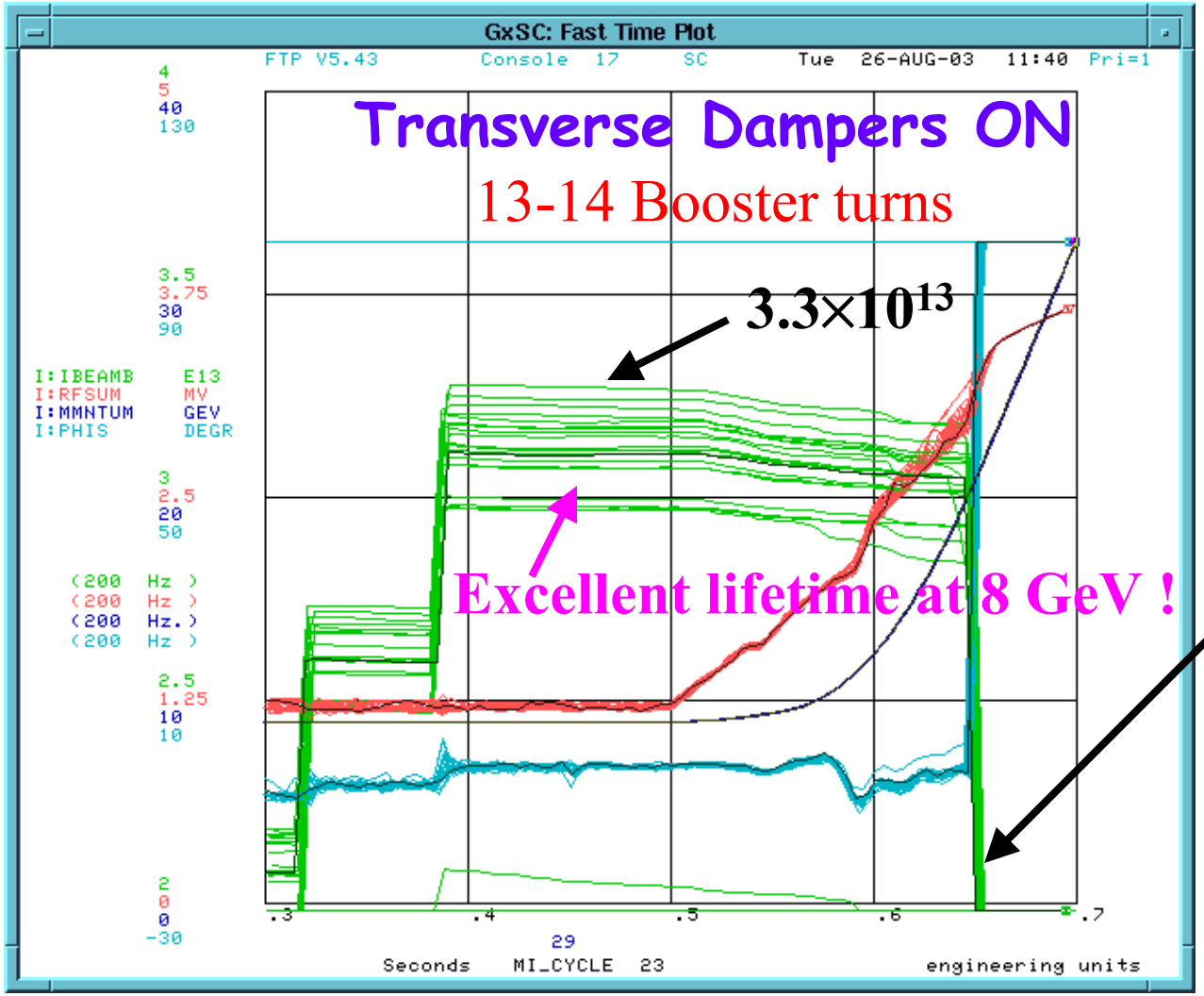
with dampers



@ 8.9 GeV/c:

ν_X=26.44, ν_Y=25.47, ξ_X=-5, ξ_Y=-5

Pushing up the intensity…



@ 8.9 GeV/c:
ν_X=26.43, ν_Y=25.47
ξ_X=ξ_Y=-5

Beam extracted at 0.65 s, just before transition, because of RF problems

NuMI beam start-up strategy in MI

- ***we will start with one dedicated NuMI cycle for a supercycle duration of 60-120 s (NuMI beam only)***
  - minimum beam intensity: 2 Booster turns, 30 bunches, equivalent to 3×10^{11} protons
  - manual control of the NuMI beam switch to allow beam
  - we will not set-up bunch rotation in the initial commissioning
- ***using this dedicated NuMI cycle we will also commission the multi-batch mode operation of NuMI, increasing gradually the number of batches from 1 to 6***
  - it is only after we are comfortable with running 6 batches at low intensity that we will switch to the mixed mode of operation NuMI/pbar stacking

➢ ***Pre-commissioning check list in MI (to be verified by the summer shutdown)***

- updated TCLK timing scheme
- notch cogging in the Booster
- final cycle with magnet ramps for NuMI multi-batch injection, acceleration and extraction
  - setting and test of extraction bumps around NuMI Lambertson magnets and kickers
- absolute measurement of the value of MI flattop momentum
- test of NuMI Lambertson magnets
- installation and test of the NuMI kickers
- installation and test of NuMI BPM electronics for 602, 604, 606 and 607 BPM's
- installation and test of beam permit inputs
  - no beam present during the rise time of the NuMI kickers
  - implementation of BPM position limits at extraction
  - limits on kicker current and voltage
  - limits on Lambertson currents